A STUDY OF SOME PROPERTIES WHICH DETERMINE THE RESOLUTION OF A LEAD-SCINTILLATOR SANDWICH ELECTROMAGNETIC SHOWER DETECTOR*

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Abstract

Using the 10-50 GeV test beam at Fermilab we have studied the resolution of a lead-scintillator sampling shower counter system as a function of energy, sampling thickness, and photostatistics to confirm a design formula $(\sigma/E)^2 = at/E + 1/N$ + other contributions, where t is the thickness of a sample measured in radiation lengths, N is the number of photoelectrons, σ is the rms energy resolution, and E is the incident energy.

Introduction

Formulas for the resolution effects of sampling thickness for electromagnetic shower detectors previously have been developed.[1-2] While designing a large electromagnetic and hadronic calorimeter system for Fermilab Experiment 605, we have decided to test general aspects of the design formula

$$\left(\frac{\sigma}{E}\right)^2 = \frac{at}{E} + \frac{1}{N} + \text{other contributions.} \qquad (1)$$

Here σ is the rms of the peak, t is the sampling length expressed in radiation lengths (r.l.), E is the incident beam energy, and N is the average number of photoelectrons. In particular, we measure the energy dependence from 10 GeV $<$ E $<$ 46 GeV, the thickness effects for 0.57 and 1.14 radiation length sampling, and photostatistics effects. Since our application is predominantly at energies 50 GeV $<$ E $<$ 400 GeV where test facilities are not readily available, we need to understand fundamental design considerations well enough to allow confident extrapolations of available designs.

We choose to test a system using polystyrene scintillator (type NE110 and NE102) coupled to a phototube via a BBQ doped acrylic wavelength shifter bar.[3] The 8 in. × 8 in. × 1/8 in. lead was interspersed with 8 in. × 8 in. × 1/4 in. (or 8 in. × 6 in. × 1/4 in.) scintillator to form a shower counter.[4] The waveshifter bar was placed on top of the resulting stack and viewed the edges of the scintillators. The phototube viewed the wavebar through an adiabatic twisted light pipe. Photostatistics could be varied by insertion of Kodak Wrattan neutral density filters between the light guide and phototube. Sampling was varied by masking alternate scintillators. The calorimeter was enclosed in a light tight box.

The trigger consisted of the coincidence of two helium Cherenkov counters to identify electrons and three beam-defining counters and the anti-coincidence of a hole counter.

The data were read in via CAMAC and was logged on magnetic tape by the program MULTI[5] running on a PDP 11/45.

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Analysis

Data were collected with beam energies of 10, 15, 20, 30, and 46 GeV. Various neutral density filters with transmissions between 1% and 80% were used. Each run consisted of ~ 1500 events. The filters were changed between most runs. This necessitated the turning off of the phototubes' high voltage and the opening of the light tight box. Therefore the phototube gain never completely settled. Portions of the runs with the worst gain drifts were cut. Then the mean (μ) and sigma (σ) was calculated and a three sigma cut about the mean was performed. This process was iterated until it converged, usually in four or five steps. To further correct for tube drift, the data were handled in 100-event subsamples.

Results

Figure 1 shows an example of our photostatistics data for 15 GeV with 0.57 r.l. sampling.[6]

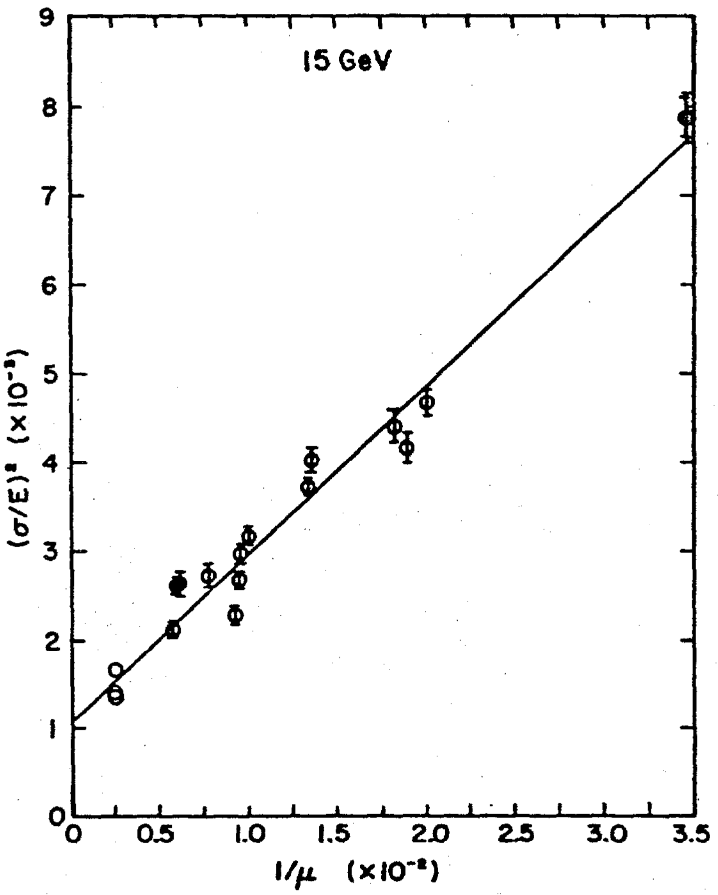

Fig. 1. Dependence of resolution on photostatistics. μ is the ADC channel number of the peak with pedestal substracted. The line is the fit to Eq. (1).

Using a fit like that shown in Fig. 1, the data at each energy are extrapolated to infinite photoelectron statistics. The resulting energy dependence of the resolution is shown in Fig. 2; μ is the ADC channel number with pedestal subtracted.

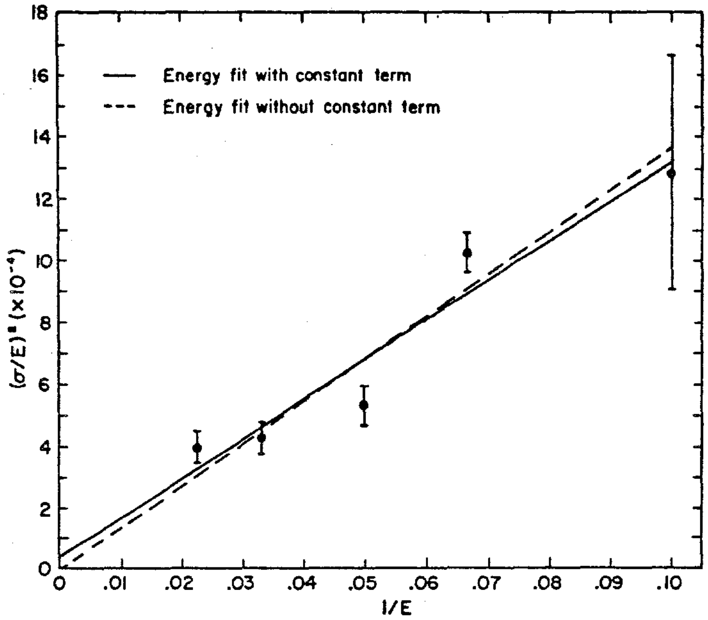

Fig. 2. Energy dependence. E is in units of GeV.

Assuming the "other contributions" from Eq.(1) to be negligible, the fit is

$$\left(\frac{\sigma}{E}\right)^2 = \frac{0.0241t}{E} + \frac{1}{N} . \tag{2}$$

Allowing for a constant independent of energy, we obtain

$$\left(\frac{\sigma}{E}\right)^2 = \frac{0.0223t}{E} + \frac{1}{N} + 4.55 \times 10^{-5} . \tag{3}$$

For a sampling of 0.57 r.l., this corresponds to a resolution of

$$\frac{\sigma}{E} \sim \frac{11\%}{\sqrt{E}}$$

at infinite photostatistics. This is somewhat larger than expected from Ref. 2 [$\sigma/E \sim 9\%/E^{1/2}$].

The resolution at our best photostatistics (no filter runs) is

$$\frac{\sigma}{E} \sim \frac{14\%}{\sqrt{E}} .$$

If we ignore the "other contributions" in Eq. (1), and multiply by the incident energy, we get

$$\left(\frac{\sigma}{E}\right)^2 E = at + \frac{E}{N} . \tag{4}$$

A plot of $(\sigma/E)^2 E$ vs. E/N for the five energies is shown in Fig. 3. The scatter of the data is larger than the statistical errors would indicate. A small decrease in the "expected μ" (calculated from the filter and the beam energy) is correlated with a large increase (degradation) of the resolution. The scatter shows no correlation with energy. The calorimeter was moved in and out of the beam line many times during this data taking, and also the alignment between the phototube and the light pipe where the filters were inserted was mechanically unstable.

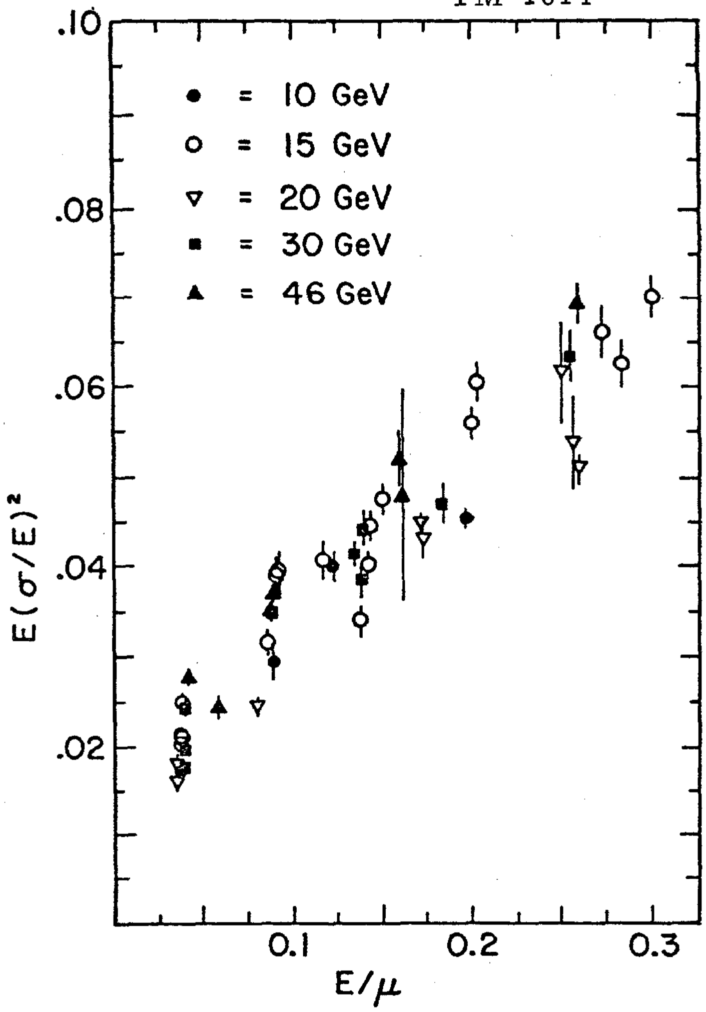

Fig. 3. Energy scaled resolution.

In the data shown so far, the absolute number of photoelectrons is unknown. The phototube we used (RCA 8850) is capable of resolving a single photoelectron peak. In order to observe this, we made a pion run (by requiring an anti-coincidence of the Cherenkov counters) and increased the high voltage of the phototube. The results are shown in Fig. 4. The

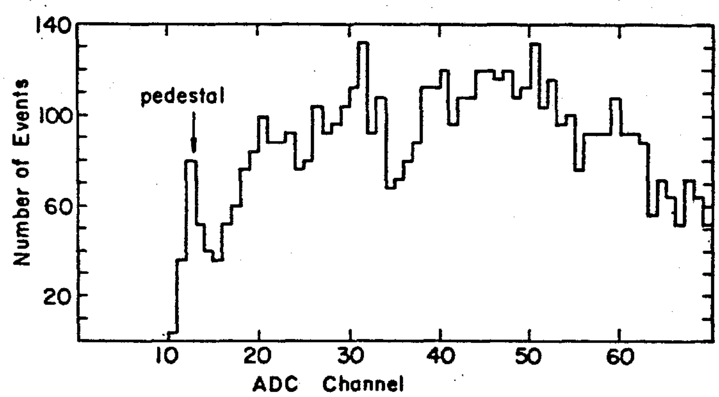

Fig. 4. Photoelectron peaks. The first peak is the pedestal.

first peak is the pedestal. Peaks at one, two, and five photoelectrons are clear. The first photoelectron peak is slightly closer to the pedestals than the separation between the other peaks. The number of channels per photoelectron is calculated by using the photoelectron peaks only. A 10 GeV electron run with an ~ 1% filter was taken with the same high voltage. With such an opaque filter, the resolution of the electron peak is dominated by photostatistics. If we write the resolution dependence as $(\sigma/E)^2 = k/N$ then the data of Fig. 4 allows us to calculate k directly. The result is $k = 1.16 \pm 0.12$ where $k = 1$ is expected from Poisson statistics.

Figure 5 shows 30-GeV data for sampling thickness of 0.57 r.l. (nominal) and 1.14 r.l. The energy

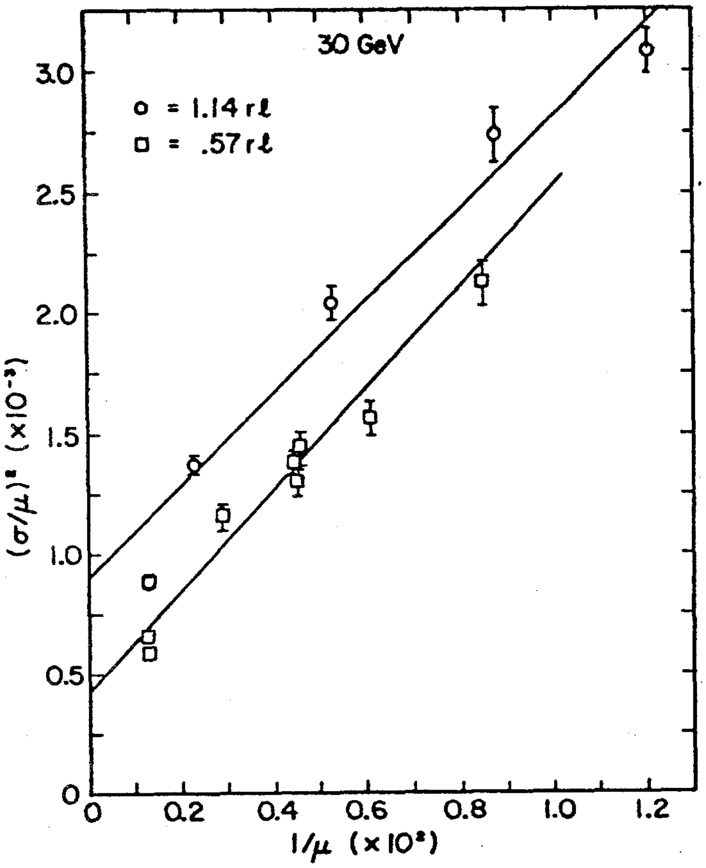

Fig. 5. Sampling length dependence.

dependence of the resolution at infinite photostatistics shows the expected $t^{1/2}$ dependence.

$$\frac{\sigma\%(0.57\ \text{r.l.})}{\sigma\%(1.14\ \text{r.l.})} = 0.66 \pm 0.09\ (0.71\ \text{expected}).$$

Conclusions

We believe the photoelectron contribution to the resolution of calorimeters is well understood. The expected Poisson behavior of the photostatistics has been verified both by the functional dependence of the resolution and by direct measurement of the single photoelectron peak.

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References

1. T. Katsura et al., Nucl. Instr. and Meth. **105**, 245 (1972).

2. V. K. Bharadwaj et al., Nucl. Instr. and Meth. **155**, 411 (1978).

3. We thank Dr. P. Rapp of Fermilab Experiment 557 for the loan of the waveshifter bar.

4. Atwood et al., SLAC-TN-76-7, December 1976.

5. L. M. Taff et al., FNAL Bison Program Notes, PN-97.

6. Note that even at light levels for which the contribution from photoelectron statistics strongly dominates no significant deviation from formula 1 is apparent. Limitations due to correlations of contributions from sampling thickness (track statistics) and photoelectron statistics will be unimportant for detectors of current interest.